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Distribution range and population viability of *Emys orbicularis* in Slovakia: a review with conservation implications

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Abstract

The European pond turtle (*Emys orbicularis*) is the only native freshwater turtle species in Slovakia. Due to watercourse regulations in the middle of the 20th century, its range became fragmented and, currently, there are only two isolated populations. From a total of 1,236 historical records in Slovakia, most observations (782 records) came from the area of the Tajba National Nature Reserve (NNR). Three of the population viability analysis models ('baseline', 'catastrophe', 'nest protection during a catastrophe') indicated the extinction of the population in Tajba, with the highest probability of extinction occurring during a catastrophic event (probability of extinction 1.00). We also evaluated information about the activity patterns of seven radio-tracked individuals and about the number of destroyed nests from the area. During the period 2017–2021, we recorded only two turtles leaving the aquatic habitat of Tajba. An alarming fact is the massive number of destroyed nests found in the area during the study period (Tajba 524; Poľany 56). Our results indicate that the population in the Tajba NNR require immediate application of management steps to ensure its long-term survival.

Keywords

Central Europe, freshwater turtle, management, threats, Vortex

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Introduction

Despite widespread conservation efforts, turtles are facing serious survival issues worldwide. The most significant threats to turtle biodiversity are caused by anthropogenic disturbances (habitat loss, habitat fragmentation, pollution and unsustainable harvesting) and by climate change (Böhm et al. 2013; Stanford et al. 2020). Given the life-history traits of turtles, which include delayed sexual maturity, low fecundity, low survival of eggs, hatchlings and juveniles and long-life span, they are vulnerable to human pressure and their ability to compensate for environmental stochasticity (including catastrophic events) is also limited (Enneson and Litzgus 2008; Spencer et al. 2017).

The European pond turtle (*Emys orbicularis* (Linnaeus, 1758)) is a freshwater turtle species inhabiting ponds, slow-flowing rivers and swamps, with a wide distribution range, extending from northern Africa through most of Europe up to the Aral Sea (Fritz 2001, 2003; Rogner 2009). In Europe, the present distribution of *E. orbicularis* is discontinuous and the species is listed as endangered in many countries (Fritz 2012). Similarly to other European freshwater turtles, the species is also experiencing demographic declines throughout its geographic distribution which are attributed to a variety of factors, such as habitat fragmentation, drying of wetlands, loss of landscape connectivity, population isolation and nest depredation (Rogner 2009). Furthermore, the co-occurrence of the invasive non-native pond sliders (*Trachemys scripta* (Thunberg in Schoepff, 1792)) within the natural ranges of *E. orbicularis*, with several countries reporting its successful reproduction, represents a serious threat to their persistence (Cadi et al. 2004; Perez-Santigosa et al. 2008; Standfuss et al. 2016; Liuzzo et al. 2020). Pond sliders can impact indigenous species through various competitions and parasite transmission (Cadi and Joly 2003; Iglesias et al. 2015; Héritier et al. 2017). The European pond turtle is also facing most of these threats at its northern range margin in Slovakia (Randík et al. 1971; Kminiak 1992; Havaš and Danko 2009).

In Slovakia, the species has been historically noted since the end of the 18th century (Korabinsky 1791), with several sites situated in the south-eastern part of the country (Stollmann 1957). The first comprehensive review of the species distribution covered the period 1862–1963 (Lác and Lechovič 1964) and was supplemented by a subsequent attempt to recognise the species' distribution, based on a questionnaire survey (Randík et al. 1971). Currently, despite of the past existence of multiple occurrences, mostly in the south-eastern part of the country, there are only two known reproducing populations in Slovakia and it is the only reptile species locally evaluated as critically endangered (Urban and Kautman 2014; Jablonski et al. 2015). Extensive alterations of the lowland agricultural landscape in the middle of the 20th century caused a radical decrease in suitable habitats for the species, which was reflected in a decline of *E. orbicularis* populations in the area (Lác and Lechovič 1964; Lác 1968; Kunaková and Terek 2016). An autochthonous population inhabiting the Tajba National Nature Reserve (NNR) has been a subject of long-term study (e.g. Novotný et al. 2004, 2008; Havaš and Danko 2009; Horváth et al. 2017) and, currently, seems to be experiencing a demographic bottleneck (Horváth et al. 2021).

Extreme environmental stochasticity, such as wetland drying, is known to have deleterious ecological and demographic effects, especially on small, isolated populations, leading to the disruption of the population structure of species and their recovery requires long periods of time (Anthonysamy et al. 2013; Keevil et al. 2018; Mullin et al. 2020). Drought conditions could force freshwater turtle species either to immigrate to other nearby water bodies or to aestivate until the next rainfall (Serrano et al. 2020). The desiccation of a marsh, where the mating of *E. orbicularis* takes place, has a direct impact on and also indirectly influences the nesting activity of females. Due to the absence of a suitable nesting habitat close to water, migrating females are imperilled by increased predation or exhaustion (Baguette and Van Dyck 2007). Today, the two main threats jeopardising the existence of this isolated population in the Tajba NNR are high rates of nest depredation and the alteration of both their aquatic (drainage) and terrestrial habitats (overgrown by the invasive trees *Robinia pseudoacacia* and *Ailanthus altissima*, as well as agricultural activities). After watercourse regulation in the region, the water level of the Tajba Marsh depends only on the amount of rainfall. Such problems indicate that this population is threatened on a multi-stage level. However, despite all the described threats, there is currently no ongoing conservation programme for the species in Slovakia. In contrast, several successful management programmes have been implemented throughout Europe, focusing mainly on nest protection, re-introduction and habitat restoration of the species (Canessa et al. 2016; Mascort and Budó 2017; Schindler et al. 2017).

Thus, for a better understanding of the current status of *E. orbicularis* in Slovakia and for the implementation of effective conservation programmes in the future, we set the following goals. First, based on the collection of all available presence data, we evaluated changes in the *E. orbicularis* distribution range in Slovakia. We further aimed to analyse the population viability of the turtle population from the Tajba NNR based on an assessment of the local demographic situation and examined the effect of a potential catastrophic event and the benefits of nest protection. For better implication of future conservation steps, the viability of this threatened population is also evaluated using information about activity patterns collected by the radio-tracking of selected individuals and about the number of destroyed nests from this area.

Materials and methods

Study area

Occurrence data on *E. orbicularis* were gathered from the whole territory of Slovakia. The case study of population viability and radio-tracking of individuals were conducted in the Tajba National Nature Reserve (NNR) in south-eastern Slovakia. The Reserve is located in the Východoslovenská Nížina Lowland, one kilometre north-east of Streda nad Bodrogom Village at an elevation of about 100 m (48°23"N, 21°47"E). Besides the Marsh (a 2.5 km long and 100–150 m wide former oxbow of the Bodrog River),

the Tajba NNR also includes 100 m of surrounding riparian zone with a total area of 27.4 ha. The study area is characterised by four habitat types: (1) Marsh densely covered by vegetation; (2) slopes of the Roháč hill covered by several tree species; (3) sandy slopes with xerophilous flora south of the Marsh; and (4) fields north of the water body used for agriculture (see Novotný et al. 2004 for details). In addition to the Tajba population, we also considered the adjacent population in Poľany (Východoslovenská Nížina Lowland, 25 km from the Tajba NNR). This population inhabits a small periodic swamp surrounded by agricultural fields. The nesting sites of the population are located at 200 m distance from the swamp on sandy slopes covered with dense xerophilous vegetation. The slopes are also used for nesting of European bee-eaters (*Merops apiaster* Linnaeus, 1758).

Collection of range data

The analysis of range changes of *E. orbicularis* in Slovakia was based on the compilation of available (published and unpublished) occurrence data of the species. We collected data on occurrence sites from 113 available sources (Suppl. materials 1) with a total of 1,236 records of the occurrence of *E. orbicularis* in Slovakia. Observations of living *E. orbicularis* individuals have been collected from 1791 to 2020. The database includes site information (village and, when available, site name or its description, coordinates and elevation), date of observation (in several cases only the year), references and/or name of observer(s). When only partial information was available about the locality, we recorded the coordinates approximately from the centre of the targeted area. As the data excerption was conducted from various sources, the plausibility of these data was critically evaluated. As a criterion of authenticity, we considered information on the documentation materials (photos, museum specimens) and also the year 1990, since then an alien species, *Trachemys scripta*, has been reported to occur in the wild in Slovakia (Čambal 1994). After 1990, only data, collected by credible people or substantiated by photo-documentation, were considered as reliable.

Radio-tracking of individuals

To investigate the turtles' spatiotemporal activity and their possible migration routes, we attached radio-transmitters (TW-3, Biotrack, UK) to the lateral carapace of seven *E. orbicularis* individuals (2 females, 3 males in 2017 and 2 females in 2020) from the Tajba NNR. To obtain their positions, we used a three-element folding Yagi antenna co-operating with a broadband receiver (ICOM IR-20). During the season from May to August, we tracked all individuals once per week. During the egg-laying period (from the last week of May to mid-June) we monitored the turtles on a daily basis. Later, from September to March, we located their hibernation position and checked them at least two times a month. The collected GPS data were processed in the QGIS 3.16 software (QGIS 2021) and shapefiles with individual spatiotemporal activity were analysed using the packages 'rgdal' 1.5–23 (Bivand et al. 2021) of the R 3.6.3 software (R Core Team 2020).

Population viability analysis

We conducted a population viability analysis (PVA) using the Vortex 10 software (Lacy and Pollak 2017), which is an individual-based model used to simulate stochastic demographic, environmental and genetic events on the dynamics of populations according to defined probabilities (Miller and Lacy 2003). We developed four models applied to the data from Tajba NNR: (1) a 'baseline' model, (2) a model simulating a 'catastrophic' event, (3) a model including 'nest protection' and (4) a model with combination of a 'catastrophe' and 'nest protection'. Parameter values for all models, including the reproductive system and rates, mortality rates, population size and carrying capacity, were set either using our own data and observations or were properly adopted from published sources, if we were unable to obtain them from our population.

The 'baseline' model was developed on *E. orbicularis* natural history records maintained for over 20 years from the Tajba NNR (see below). The model was simulated 1,000 times over a time-frame of 140 years to cover at least two generations and to see relatively short time changes of the simulated models. We defined extinction as occurring when only one sex remains. Although there are no genetic data for our population, we did not include any inbreeding depression, as evidence of inbreeding in chelonians is rare (Kuo and Janzen 2004; Pittman et al. 2011). Furthermore, we assumed that environmental variation affects reproduction and survival equally. As evidence of density-dependent reproduction is uncommon in chelonians (Shoemaker et al. 2013), we did not include any density-dependent growth in this baseline model. Input parameters (Table 1) for all models were set as follows.

'Reproductive system': European pond turtles are a polygamous and long-living species, reaching sexual maturity at different ages depending on their sex and living conditions. Reported species longevity is 60 or even 120 years, but the exact maximum lifespan in the wild remains unknown (Rogner 2009). We assumed that the probability of surviving to 120 years in the wild is very low; therefore, we reduced the maximum age estimate to a more realistic value (60 years). The sex ratio at birth cannot be determined, because the sex of *E. orbicularis* juveniles is not possible to determine until they reach four or five years of age (Rogner 2009).

'Reproductive rates': In general, only a small proportion of females breed in any given season and this is directly related to environmental conditions (Fritz 2012). This proportion corresponds to our input data obtained from the number of females found nesting in favourable years (23 females in 2017) compared to the number of females (6 females in 2020) during dry, unfavourable years in the Tajba NNR. A maximum number of 25 eggs in one clutch was recorded in 2013 and the mean was about 12–13 eggs; the lowest recorded number of eggs per clutch was six (Novotný et al. 2004 and own unpublished data).

'Mortality rates': Mortality during the first year of life was based on the number of observed depredated nests around the Tajba NNR. All of the other mortality data were fitted from the available literature (Table 1). The higher mortality rate of adult females was based on the current sex ratio of the population (F:M = 1:1.3; own unpublished data).

Table 1. Vortex life history parameter inputs of *E. orbicularis* in the Tajba NNR, employed for the baseline population viability analysis model.

parameter	value	source
Species description		
Inbreeding depression	no	
EV Correlation between reproduction and survival	1	
Reproductive system		
Breeding structure	polygamous	Rogner 2009
Age of First Reproduction for Females	10	own unpublished data
Age of First Reproduction for Males	7	own unpublished data
Maximum age of reproduction	60	Rogner 2009
Maximum lifespan	60	Rogner 2009
Maximum Number of Broods per Year	2	Novotný et al. 2004
Maximum number of progeny per brood	25	Havaš et al. 2018
Sex ratio at birth	50	Rogner 2009
Density Dependent Reproduction	no	Shoemaker et al. 2013
Reproductive rates		
Adult Females Breeding	29.7%	own unpublished data
EV in Breeding	1.8%	own unpublished data
Distribution of broods per year	brood 1: 85% brood 2: 15%	Bona et al. 2012
Distribution of number offspring per female per brood	normal distribution	
Mean clutch size/SD	13/5,9	Novotný et al. 2004, own unpublished data
Mortality rates		
Mortality of females		
Mortality from age 0 to 1	98%	own unpublished data
Mortality from age 1 to 2	80%	fitted from Canessa et al. 2015; Rivera and Fernández 2004
Mortality from age 2 to 3	50%	
Mortality from age 3 to 4	20%	
Mortality from age 4 to 5	10%	
Mortality from age 5 to 6	10%	
Mortality from age 6 to 7	10%	
Mortality from age 7 to 8	4%	
Mortality from age 8 to 9	4%	
Mortality from age 9 to 10	4%	
Mortality after age 10	1.4%	
SD in mortality from age 0 to 10	1%	Rivera and Fernández 2004
Mortality of males		
Mortality from age 0 to 1	98%	own unpublished data
Mortality from age 1 to 2	80%	fitted from Canessa et al. 2015; Rivera and Fernández 2004
Mortality from age 2 to 3	50%	
Mortality from age 3 to 4	20%	
Mortality from age 4 to 5	10%	
Mortality from age 5 to 6	10%	
Mortality from age 6 to 7	10%	
Mortality after age 7	1%	
SD in mortality after age 7	0.7%	
SD in mortality from age 0 to 6	1%	Rivera and Fernández 2004
Mate monopolization		
% of males in breeding pool	100	
Initial Population Size		
Initial Population Size	178	own unpublished data
Age distribution	Specified age distribution	
Carrying capacity		
K	500	estimated according Balázs and Györffy 2006
SD in K due to EV	5	

'Population size': To estimate the population size, we used a long-term dataset from 1996–2020. During the last sampling in 2020, no individuals of 1–4 years old were discovered. We, therefore, modified the stable age distribution default value according to this fact, using a specified age distribution.

'Carrying capacity': We included a carrying capacity of 500 ± 5 turtles, estimated from a density of 142–228 individuals per hectare in Hungary (Balázs and Györffy 2006).

Contrary to the 'baseline' model, in the model including one 'catastrophic' event, we set the desiccation of the Tajba oxbow with a frequency of 5%. The last time the Marsh dried up happened 25 years ago and, in a 140-year simulation, it could occur five times. The severity of reproduction and survival were set to values 0.75 and 0.50, respectively. In the 'nest protection' model, we decreased the mortality rates of the age 0 to 1 from 98% to 70%. Finally, in the combination of these two models, we simulated the effect of nest protection during a catastrophic event. The final Vortex output files were visualised using the R-package 'ggplot2' 3.3.2 (Wickham 2016).

Results

Range change

The first observations of *E. orbicularis* individuals date from 1791. More data came from 1919, but they were still scarce until the end of WWII and do not allow a full description of species distribution range in the study area to be made. Later on, thanks to the dedicated work of J. Lác and A. Randík (Lác 1967; Randík et al. 1971), the distribution range of *E. orbicularis* in Slovakia became delineated. During the period 1946–2000, we found 358 records, most of them originating from the work of Randík et al. (1971). These data were the results of the authors own observations and an extensive questionnaire survey in the Michalovce District from 1965. During the next period (2001–2020), observations of *E. orbicularis* individuals were much more abundant (838 records), mainly from the area of eastern Slovakia (Figure 1). From a total of 1,236 records in Slovakia for the whole study period, 822 records are from the vicinity of Streda nad Bodrogom and 782 records were made from the area of the Tajba NNR. Most of the records (552) from the Tajba NNR are from the period of 2001–2005 (Figure 2). Besides this long-studied population in the Východoslovenská Nížina Lowlands, in 2011, a new reproducing population was discovered in the vicinity of Poľany. The only complex study on the current distribution of *E. orbicularis* in Slovakia, focusing mainly on the western part of the country, mentions 16 sites in the Danubian and Záhorská Lowlands after 2001 (Jablonski et al. 2015). The recent distribution of the species is restricted mainly to the area of the Východoslovenská Nížina Lowlands (14 sites) and to the floodplains of the River Ipeľ (5 sites). However, most of these records are just occasional findings of single individuals, likely not viable populations. Thus, the two currently recognised populations, in western and eastern Slovakia, respectively, are isolated and located in a fragmented wetland landscape.

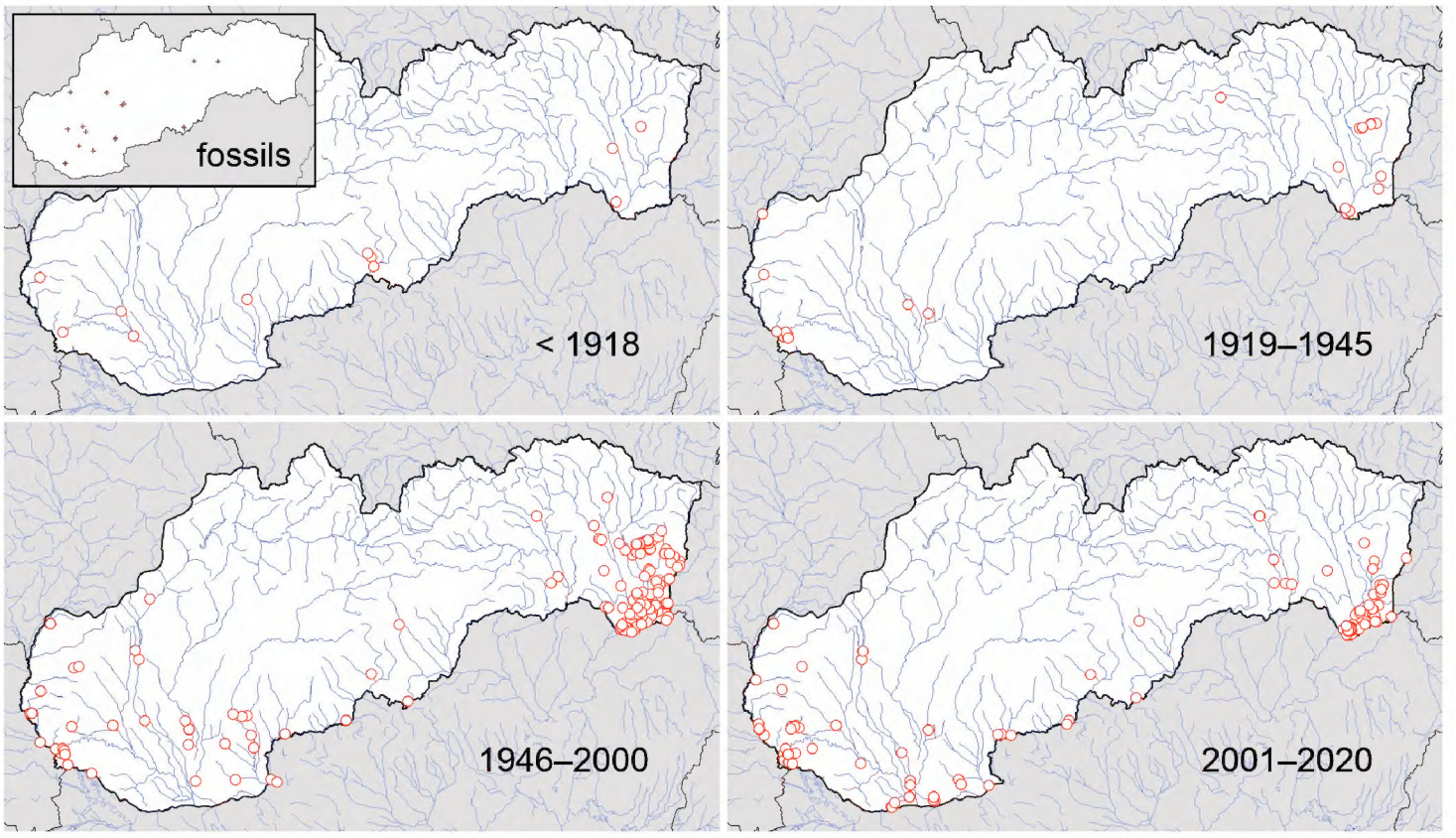

Figure 1. Distribution range of *E orbicularis* in Slovakia. The division into periods follows the phasing of herpetological research in Slovakia (Uhrin et al. 2019), the range based on fossil records originating from the Pliocene up to the Holocene (for source references, see the Suppl. materials 1).

Population in Tajba NNR

In the period 1996–2020 in Tajba, a total of 178 individual turtles were identified. They were 102 females, 67 males and 9 juveniles between age 1–15 years and more. Adults were sexed using secondary sexual characteristics (Rogner 2009). However, there were 47 cases of turtle for which we were unable to determine their exact age, so they were classified as old. We also recorded 77 recapture events of 40 individuals during the study period, with 18 individuals recaptured more than once. Additionally, the numbers of 524 destroyed nests around the nesting sites in Tajba and 56 destroyed nests in nearby Poľany population were observed (Figure 3).

Radio-tracking

During the study period, there were two records of individual turtles leaving the aquatic habitat of Tajba. In all other cases, the monitored turtles were moving within the water habitat. In one case (18 October 2018; ID216), we found the transmitter detached on a nearby meadow ~ 150 m from its last recorded position (27 September 2018) in the water habitat. In 2020, we recorded the migration of one female turtle (ID10) from the water habitat to a nesting site and back. The migration to the nesting site took place between 25 May and 6 June 2020 with ~ 1.5 km moved distance and the female was back in the water during one day. Furthermore, we located six turtles' hibernacula. During the 2017/2018 season, all of the five monitored turtles hiber-

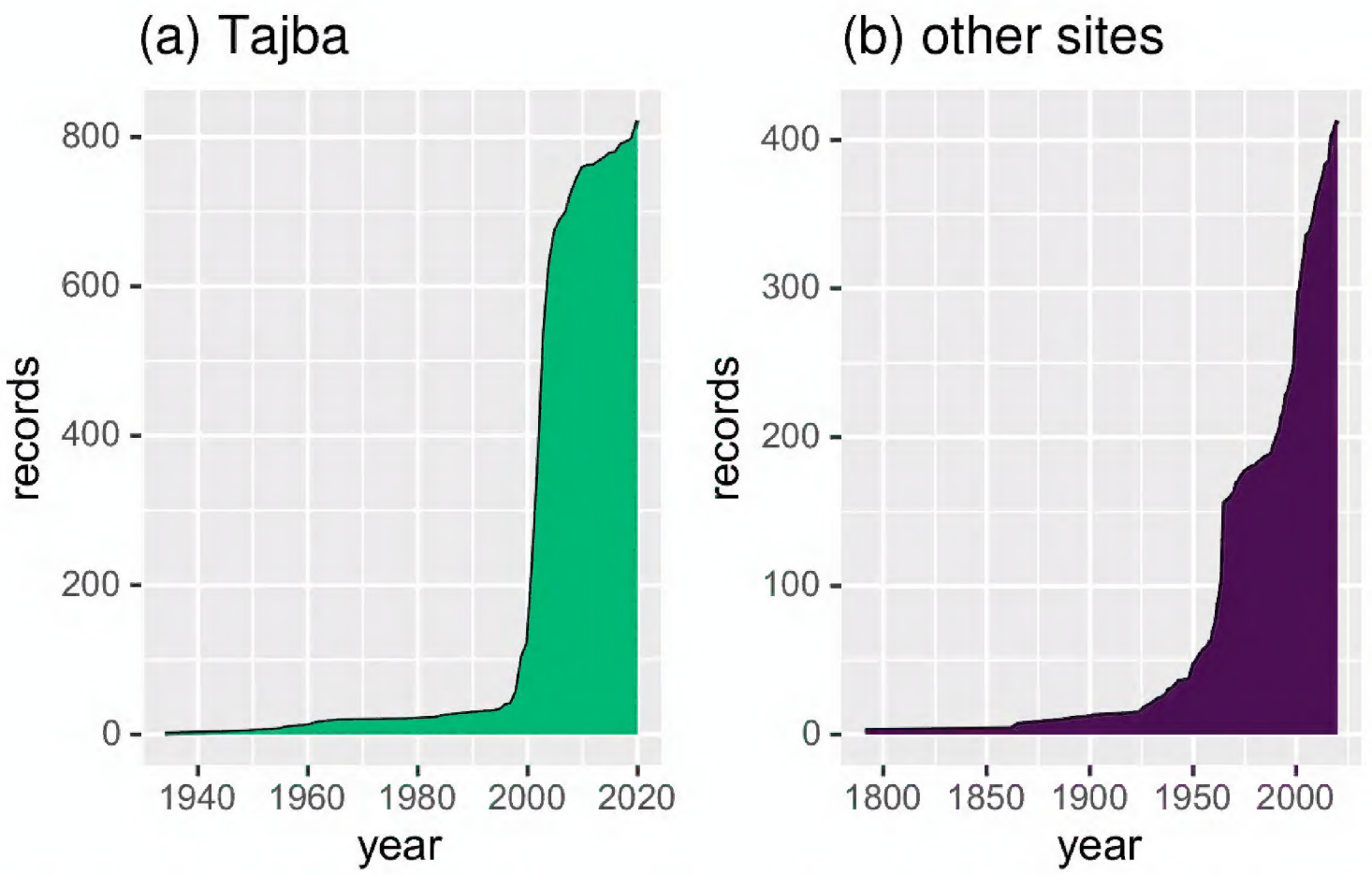

Figure 2. Cumulative plots of (**a**) all distribution data in the Tajba NNR and (**b**) other sites in Slovakia.

nated under the ice sheet and first became active on 28 March 2018. In 2019/2020, we identified the hibernacula of two turtles (ID215, ID213), one of which (ID213) was buried in the mud from 20 September 2019 without any water cover until 18 February 2020. The monitored turtles became active on 10 March 2020. During the 2020/2021 season, the two monitored turtles (ID213, ID10) ended their hibernation on 9 March 2021. In 2018 and 2019, we found two transmitters detached and two other transmitters stopped signalling in 2019 and 2020. All of the recorded observations are shown in Fig. 4.

Population viability analysis

Vortex's standard output of PVA provided the probability of population extinction within 140 years. Median and mean time to extinction for populations that became extinct during the simulations, mean growth rate (r) and the average population size were estimated at 140 years. The baseline model yielded a declining population ($r = -0.054$), with nearly all of the populations becoming extinct (Figs 5 and 6). The only case when the population persisted and indicated an increase in growth rate ($r = 0.008$) was that of the 'nest protection' model. Populations were exposed to the highest probability of extinction (1.00) in the case of 'catastrophe', when all of the populations became extinct. Although the implication of nest protection during a catastrophic event yielded longer survival, the probability of extinction still remained high (0.608). All of the output results are summarised in Table 2.

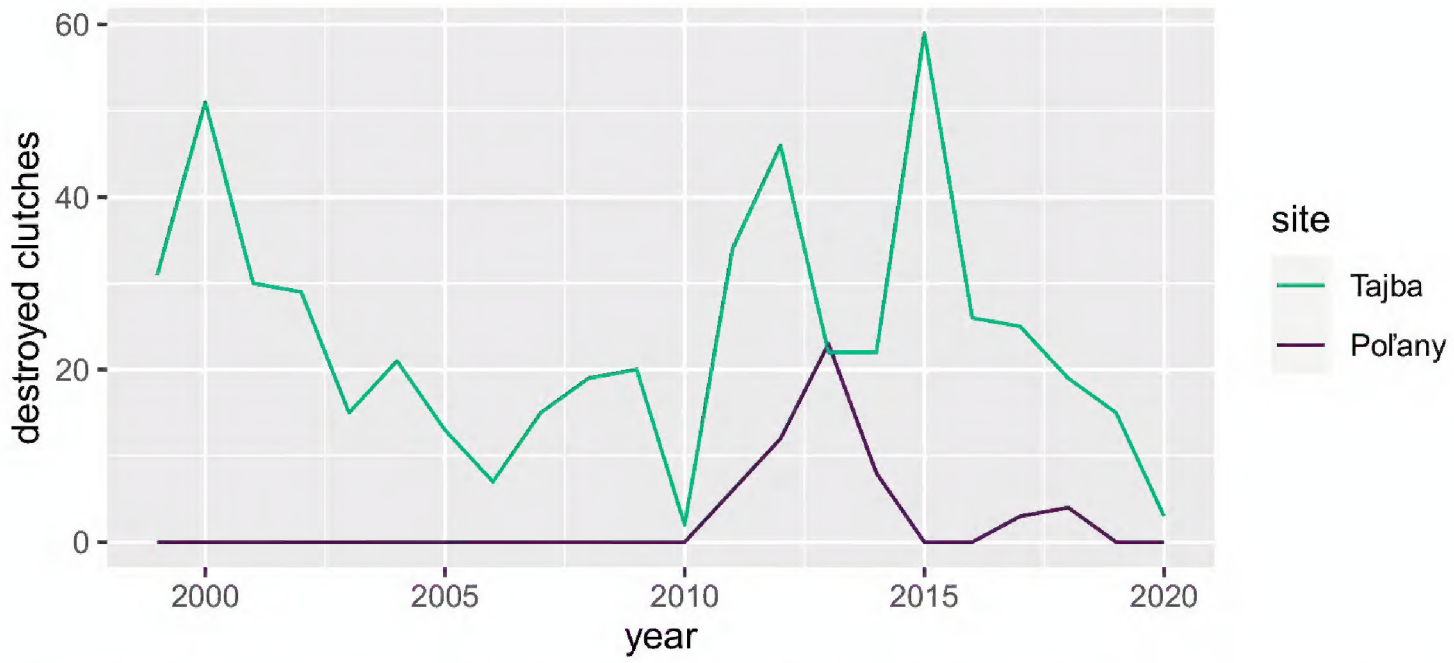

Figure 3. Plot of destroyed clutches found at the nesting sites in the Tajba NNR and in Poľany during the period 1999–2020.

Discussion

Literature sources dealing with the distribution of *E. orbicularis* in Slovakia allowed us to make an assumption about its accurate distribution range only in the middle of the 20th century. Comparing recent distribution data to the available fossil findings ranging from the Pliocene to the Holocene, the range of the species today is likely more reduced and fragmented. The more northern historical distribution of *E. orbicularis* in Europe was the result of the favourable early Holocene climate, when the species reached its maximum range extension (Sommer et al. 2007). Its recent range is limited by climatic factors and by the species habitat preference for the lowlands of mainly eastern Slovakia, with just two or three confirmed reproducing populations (Jablonski et al. 2015). As most of the findings (with the exception of the Tajba NNR and Marcelová, in eastern and western Slovakia, respectively) are sporadic or accidental observations of single individuals and no further nesting sites have yet been discovered, it is almost impossible to determine the origin of the recorded turtles. Even the population in Marcelová needs further genetic studies for the verification of its autochthony. Other recent observations reported from western Slovakia are listed and discussed in detail in Jablonski et al. (2015). Another noteworthy region in south-western Slovakia, from where regular reliable observations of single individuals are made, is located at the floodplains of the River Ipeľ. The close location of the population in Danube-Ipoly National Park, Hungary, suggests possible migration of the species to this area (S. Bérces, pers. comm.). Fragmentation of the species' distribution range due to habitat deterioration is further supported by the fact that the population discovered in Poľany diminished within four years. Destroyed clutches were discovered again in 2017 and 2018, but in the last two years, the adjacent wetland has dried out and no turtle activity has been observed in the area. The fate of the population remains unknown, as no turtle observation has been

Table 2. Summary of the results of the simulated population viability models.

Model	Prob of Extinct	Time to first extinction (median)	Time to first extinction (mean)	Mean growth rate (r)	N in all pops (mean)
Baseline	0.999	76	76.84	-0.0539	0.02
Nest protection	0.00	-	-	0.0078	428.26
Catastrophe	1.00	52	51.96	-0.0786	0
Nest protection + Catastrophe	0.608	124	92.92	-0.0271	15.38

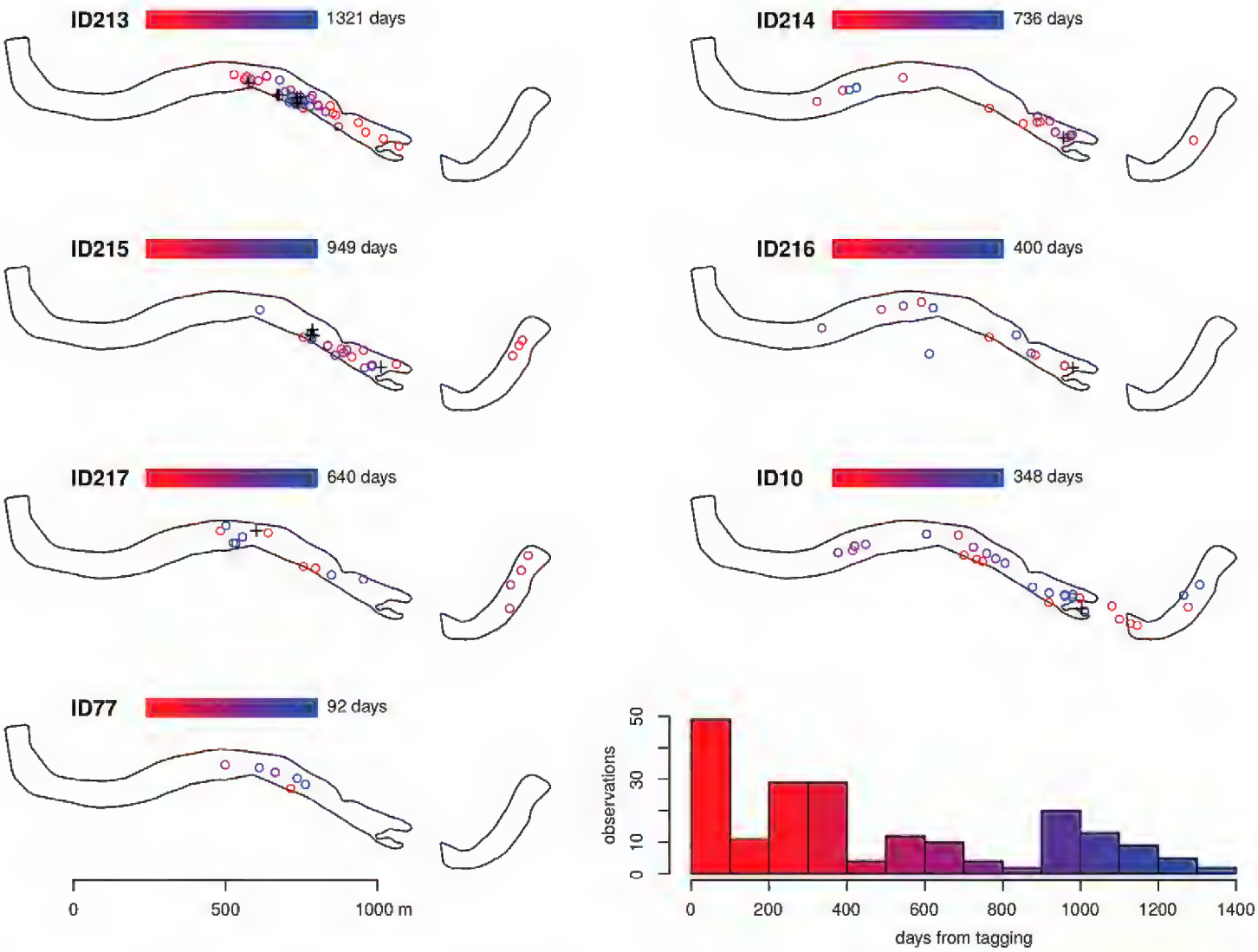

Figure 4. Representation of the locations (open circles) and hibernacula (crosses) of the tagged turtles in the Tajba NNR. The colour scheme represents the number of days elapsed from the day of tagging.

reported from the vicinity of Poľany since 2017. Observations of single turtle individuals are relatively common in the Východoslovenská Nížina Lowland, especially from the Medzibodrožie Region. These individuals are probably the still surviving remnants of past existing populations, although no comprehensive monitoring activities are being carried out in the Region. For this reason, the implementation of such species monitoring should be a priority in the future.

Despite this decreasing and fragmented distribution and the fact that the mostly known and still reproducing *E. orbicularis* population in the Tajba NNR is in decline, the last conservation activity was carried out in 2002–2006, with most of the turtle observations made during that time (Burešová et al. 2001). Although even small populations

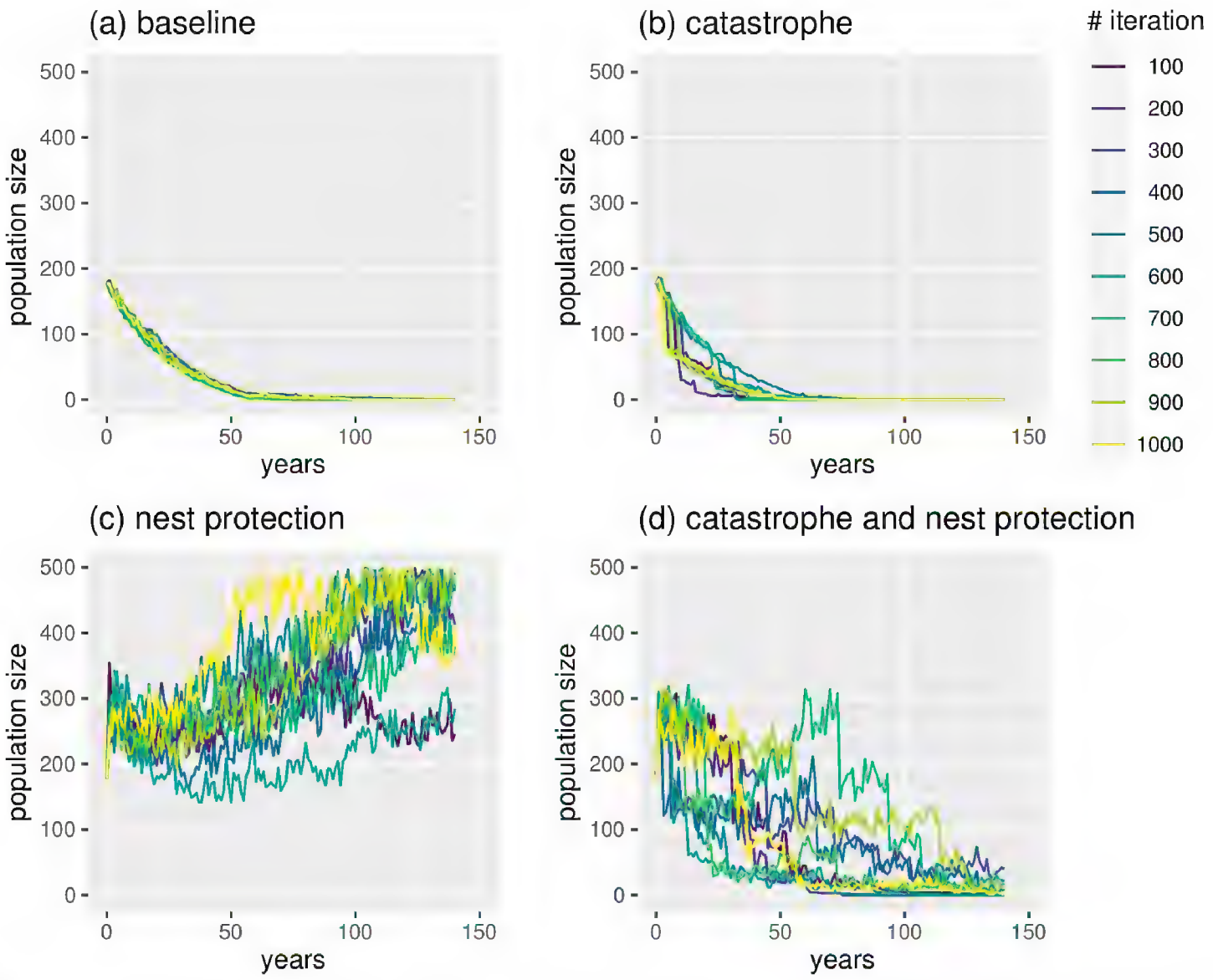

Figure 5. Fluctuation of selected (every hundredth) iterations of the simulated population viability models.

can persist for long periods of time, the existence of high-quality habitat conditions are inevitable (Folt et al. 2021). The results of our population viability analysis support the importance of suitable habitats. We found that the population projected during a 'catastrophic' event had slightly higher probability of extinction than our 'baseline' model. Although, the populations became extinct in both of the simulated models, during a 'catastrophic' event, it happened 24 years earlier. The only PVA for *E. orbicularis* was conducted on a population from north-western Spain, in which a 'catastrophic' event decreased their survival probability in 100 years to 8%. Simulations were employed on a population with a lower initial population size than in our simulation, but it was also male-biased (Cordero Rivera and Ayres Fernández 2004). Similar results were obtained by Famelli et al. (2012); a 'catastrophic' event led to a 99% extinction probability for the Maximilian's snake-necked turtle (*Hydromedusa maximiliani* (Mikan, 1825)) population in Brazil. Unfortunately, the negative impacts of habitat drying are already visible on our studied population. In the last decade, the water surface of the Tajba Marsh has been drastically reduced, losing more than half of its initial area. Due to these unfavourable conditions, aestivating individuals have been regularly observed since 2009 and more frequently in the last few unusually dry years. One tagged individual buried in the mud for more than five months was exposed to very low winter temperatures (-10 °C) during

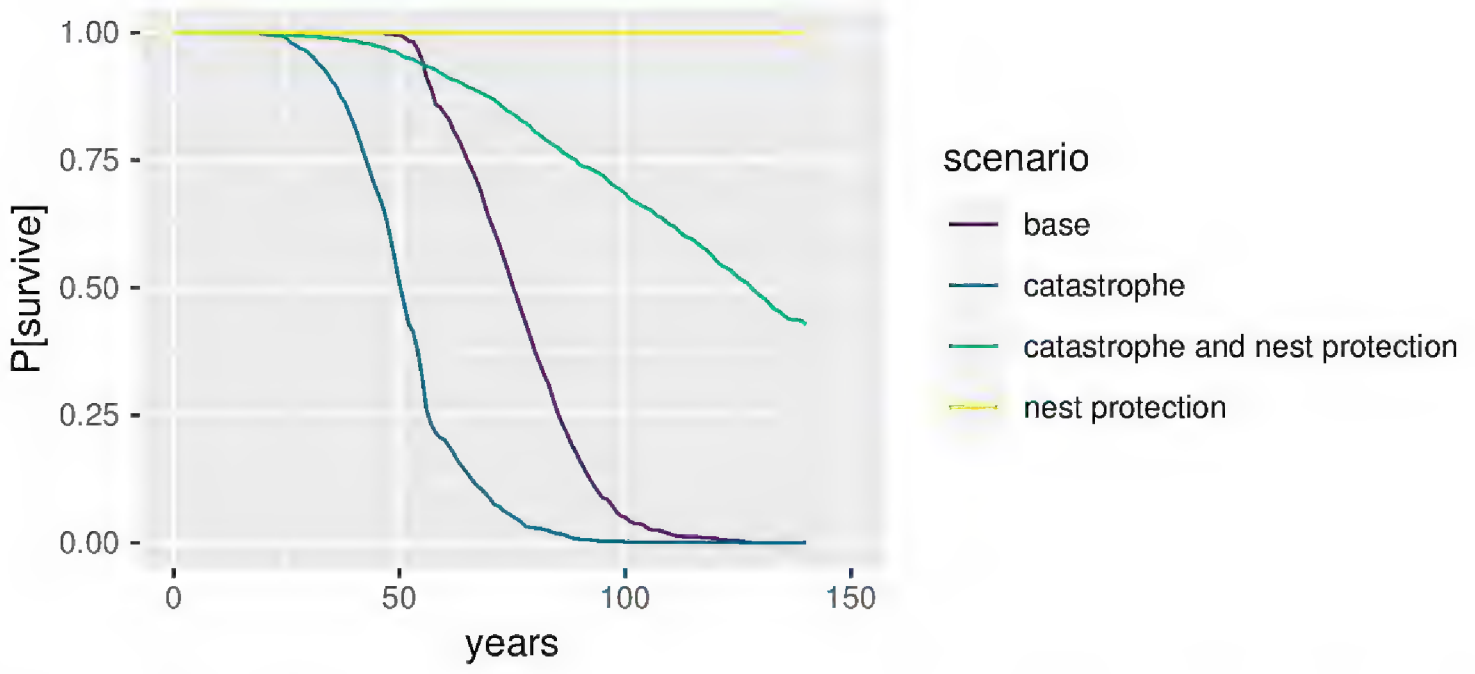

Figure 6. Probabilities of survival rate with displayed trajectories of the mean time of the first extinction in the simulated population viability models.

its hibernation period; however, the critical minimum temperature for adult turtles is known to be – 2 °C (Hutchison 1979). While long-distance migration of *E. orbicularis* individuals to overwintering sites was detected in France (Thienpont et al. 2004), we did not observe this strategy in any of our tagged individuals. In addition, *E. orbicularis* populations inhabiting the Tordera River system in north-eastern Spain showed high fidelity to their capture sites with low dispersal movements between neighbouring water habitats (Escoriza et al. 2020). An unusually long migration of a female *E. orbicularis* individual was recorded by Bona et al. (2012); the turtle migrated about 5 km distance from the Tajba NNR and then returned. During our radio-tracking survey, we were unable to detect the final destination of the only possible migration attempt to a more suitable water habitat, as we only found the detached transmitter. We speculate that the female was heading to the nearby Somotorský Canal, in which regular *E. orbicularis* observations are made.

Both of these strategies (aestivation or migration) could influence the adult survival of the population, which is especially important for the population persistence of long-lived species (Howell and Seigel 2019); high adult survival is essential to compensate for low hatchling survival (Enneson and Litzgus 2008). Studies have shown that turtle populations are unable to sustain more than 2–3% annual adult additive mortality (Gibbs and Shriver 2002), which is also, based on our long-term observations, a realistic scenario for the population in the Tajba NNR. Due to shallow water levels, the turtles could be exposed to increased adult predation (Hall and Cuthbert 2000). These habitat conditions are suitable for wild boars (*Sus scrofa* Linnaeus, 1758), whose impact is already detectable on the turtle population in the Tajba NNR. However, predation by wild boars is recognised especially on nests and young individuals (Zuffi 2000; Ibáñez et al. 2018). In 2020, three adult turtles (2 females, 1 male) were observed with multiple injuries caused presumably by this predator. Female turtles are at even higher risk, because due to the desiccation, they have to reach distant nesting sites mainly on land, which we were able to

prove by radio-tracking. According to this observation in 2020, the turtle moved ~1.5 km in a week, mainly on land, in an effort to reach the nesting site. While the upper limit of terrestrial movement for *E. orbicularis* is recognised to be less than 2 km (Ficetola et al. 2004; Pereira et al. 2011), terrestrial movements for nesting were also detected in other parts of their range, however, to shorter distances (Rovero and Chelazzi 1996; Kotenko 2000; Cadi et al. 2004). We also observed a great decrease in the total number of nesting females. While in 2017, more than 20 females were nesting, in 2020, just five females were found. Most studies on the nesting ecology of the European pond turtle are focused on other aspects of nesting (Meeske 1997; Mitrus 2006; Najbar and Szuszkiewicz 2007). The number of depredated nests is also massive in the area: during the period 1999–2020, more than 520 destroyed nests were found, causing very high rates of hatchling mortality. According to our PVA model, a reduction in hatchling mortality by about 30% (from 98% to 70%) would mean the survival of the population, with none of the simulated populations becoming extinct. Even during the simulated catastrophic event, protection of the nests postponed the time of the first extinction (Table 2). For the long-term viability of the olive ridley turtle population (*Lepidochelys olivacea* (Eschscholtz, 1829)), securing high emergence success of hatchlings was shown to be essential (Maulany et al. 2017). In the Tajba NNR, square metal grids were used for predation exclusion, but with low efficiency due to the extensive area of the nesting sites (~ 5 ha). Therefore, we recommend testing the suitability of chemical deterrents to reduce hatchling mortality. On the other hand, the implementation of nest protection grids enabled a population increase in the Donau-Auen National Park, Austria (Schindler et al. 2017). The high mortality rate of hatchlings is already reflected in the demographic structure of the population. Our observations showed a general shift towards a presumably old population. During the last sampling occasions and observations in 2020, no 1 to 4-year-old individuals were discovered; furthermore, in the years 2018–2020, we found only one hatchling per year. An adult dominated *E. orbicularis* population was described in Algeria (Fediras et al. 2017), in contrast to two populations in the Tordero River, where juveniles accounted for more than 20% and 10% of the captured specimens, respectively (Escoriza et al. 2020).

All of these alarming threats to the population in the Tajba NNR require immediate application of management steps to ensure the long-term survival of this unique population. Therefore, we recommend the application of the following conservation measures in the near future.

Management recommendations

Amongst others, for maintaining viable population dynamics, the habitat requirements of the species need to be fulfilled. This includes the existence of permanent wetlands surrounded by woodland habitats serving the terrestrial activities of turtles for nesting and migration (Ficetola et al. 2004).

'Nest protection'. To reduce nest predation rates, various types of predator exclusion devices are designed for a wide range of freshwater and marine turtle species (Riley and Litzgus 2013; Buzuleciu et al. 2015; Schindler et al. 2017). Until now, square metal grids

attached to the ground (similar to design C presented by Schindler et al. 2017) have been used for the protection of turtle nests in the Tajba NNR. Unfortunately, because of the size of the nesting site (40 ha of scattered area), nest protection by this approach seems inefficient. Therefore, to control nest depredation, we recommend the application of chemical repellents all over the nesting site, with re-application in certain time periods, to ensure the protection of a larger number of nests. Further, for the protection of egg-laying sites, the current protected buffer zone around the Marsh (100 m) needs to be extended. According to the turtles' migratory capabilities, a buffer zone of terrestrial habitats at least 1–1.5 km wide is required around the water habitat (Ficetola et al. 2004).

'Restoration of water regime'. Drainage of the Marsh represents a major threat for the viability of the species; therefore, assuring the wetland's permanent water regime is essential. Due to anthropogenic modifications of the Slovak lowlands in the last century, the Marsh was cut off from its neighbouring water sources from rivers (River Bodrog) and even from canals. To stop desiccation of the Marsh, we need to reconnect these water habitats. For the restoration of the water regime of the Tajba Marsh, the rebuilding of some river canals and/or construction of culverts must take place in the area, along with previous sediment dredging, to ensure a long-term restoration success.

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Supplementary material 1

Dataset of presence data and fossil records of *Emys orbicularis* in Slovakia

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Data type: Species data.

Explanation note: Dataset of presence data and fossil records of *Emys orbicularis* in Slovakia.

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